The Deep Ultra-Violet Free Electron Laser

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National Synchrotron Light Source

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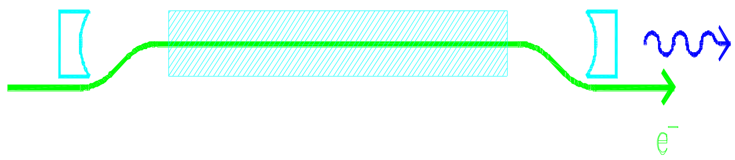
Outline

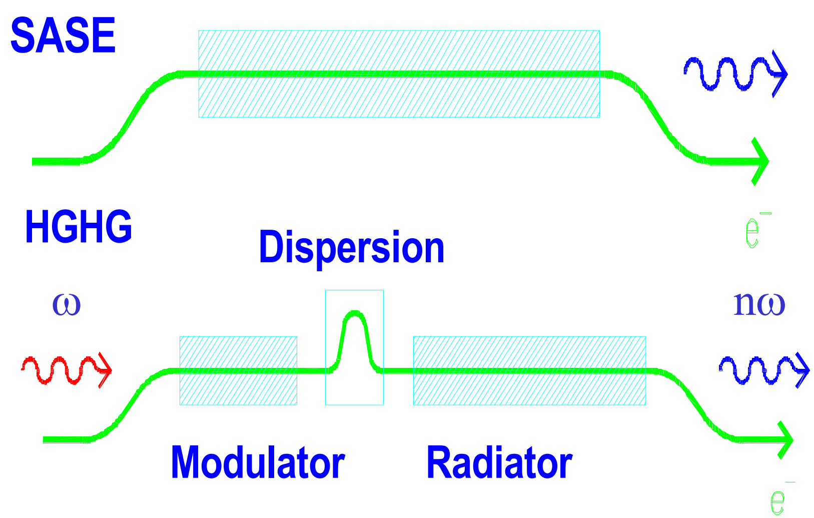
- Introduction
- DUV-FEL Facility
- Recent Experimental Results – SASE and HGHG
- DUV- FEL user science program – ion pair imaging experiment
- Future upgrade and Summary

Free Electron Laser Configurations

OSCILLATOR



SINGLE PASS FEL



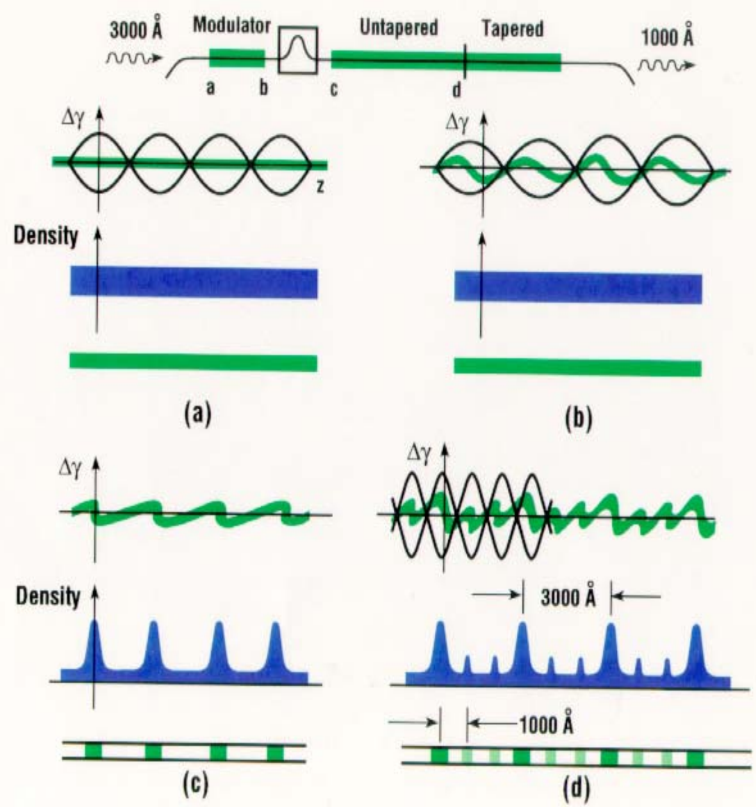
Challenges:

1.Oscillator produces fully coherent output; but there is no High-quality mirrors in UV and X-ray range.

2. SASE output covers full spectrum, but it is only transverse coherent.

3. HGHG is capable of producing fully coherent output, seed laser limits its spectra coverage.

High Gain Harmonic Generation (HGHG) Principle



HGHG has the following advantages:

- Longitudinally fully coherent
- Narrower bandwidth than SASE
- Larger ratio of output/spontaneous radiation
- Central wavelength is stable
- Pulse length is short & controllable (20 fs)
- Output fluctuations can be reduced

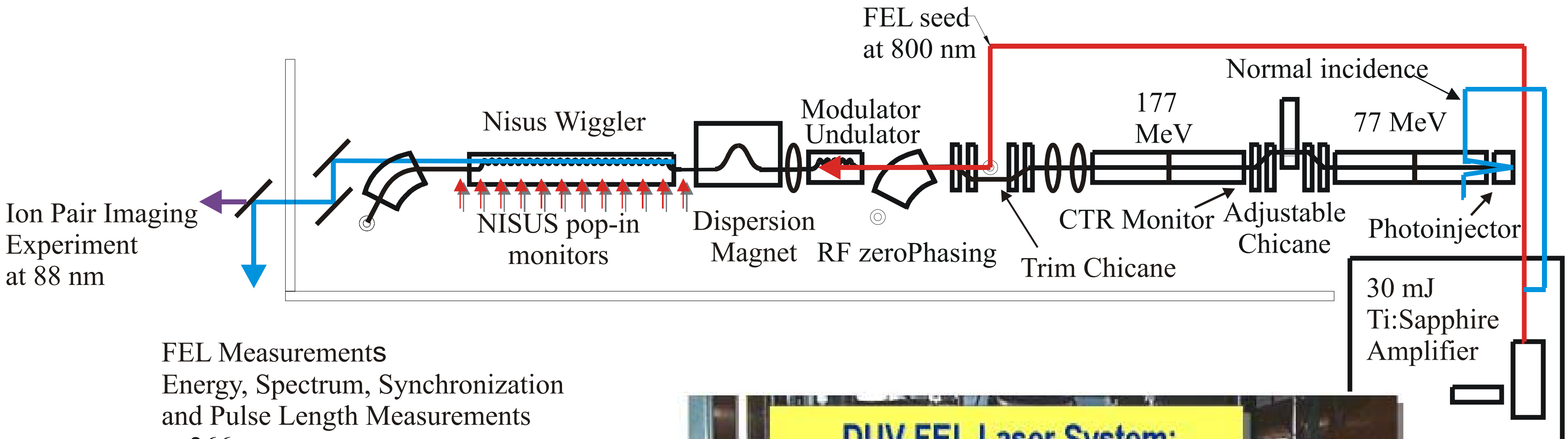
DUV – FEL Facility

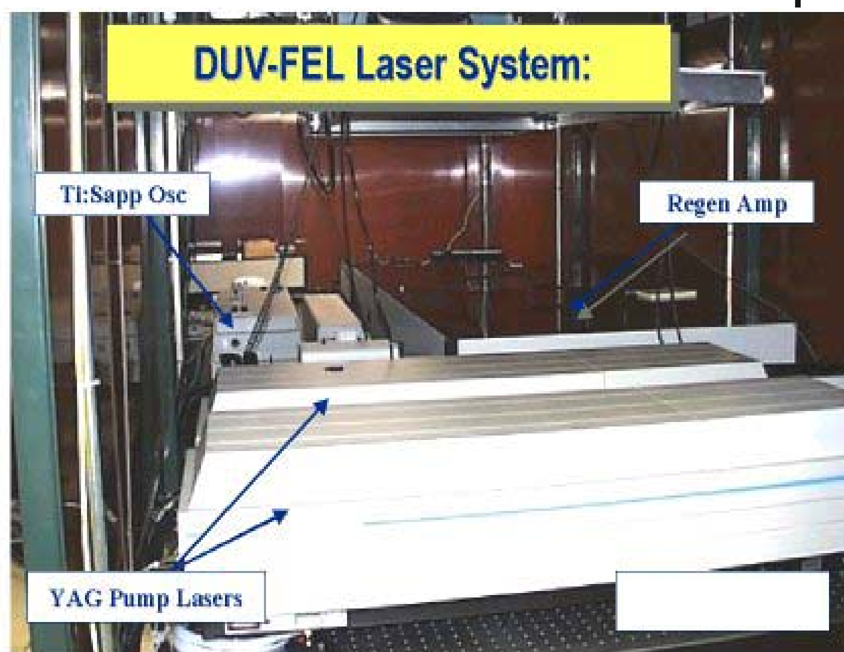
- A ***dedicated*** **platform for the development of single-pass FEL Science and Technology, and its applications.**
- **The *only* short wavelength FEL project based on Laser Seeded High Gain Harmonic Generation**
- **Many *collaborative* relationships: BNL-ATF, APS, SLAC-LCLS, TJNAF-FEL, Duke, U. Maryland, TESLA**

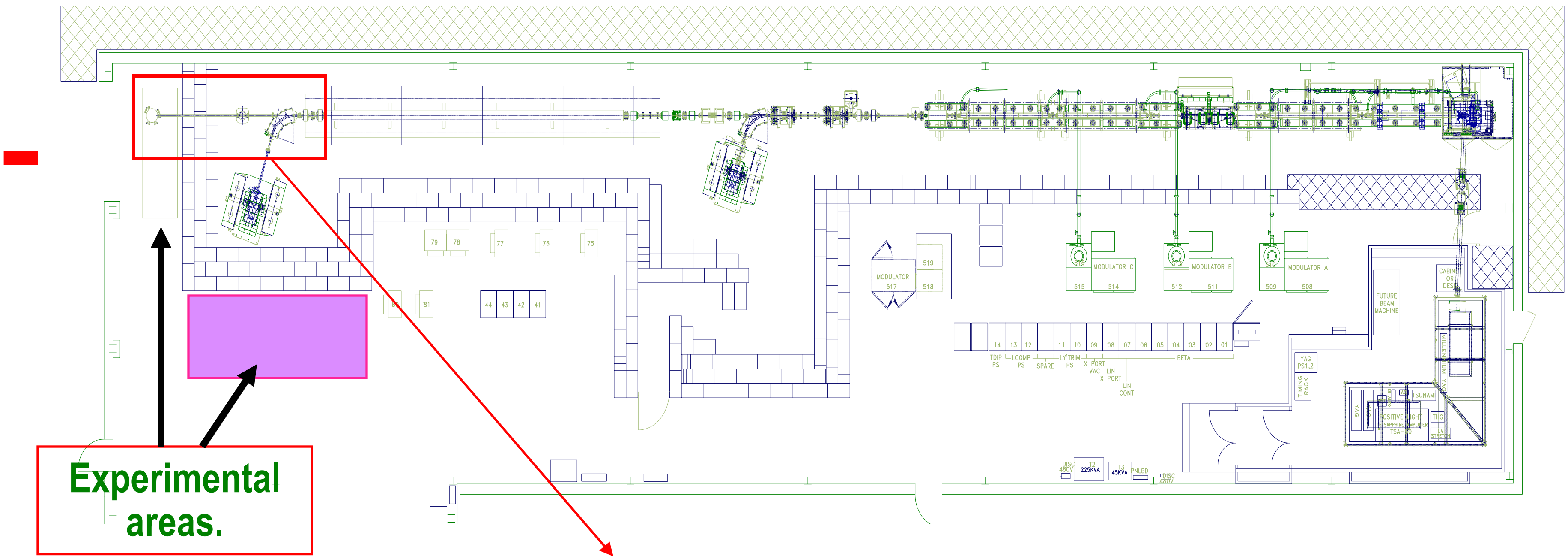
DUV – FEL Facility

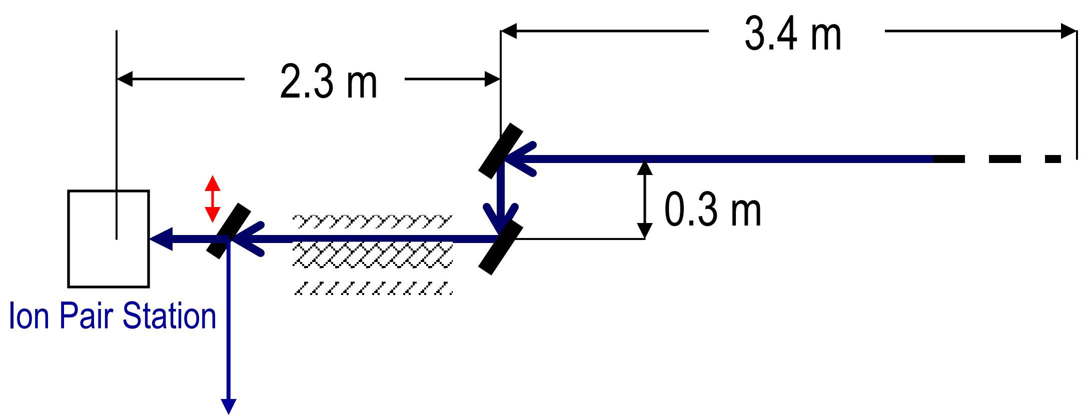
- High-Brightness femto-second electron beam.
- Synchronized femto-second laser beam.
- Sophisticated electron beam and laser instrumentation
- HGHG FEL:

Electron Energy (MeV)	176		Peak Current (A)	300
NISUS Period λ_U (cm)	3.89		NISUS length (m)	10
Seed laser λ_S (nm)	800		Seed laser pulse length (FWHM) (ps)	0.1 - 6
Energy/pulse at 266 nm (μJ)	**100**		**Energy/pulse at the 3rd harmonic 89 nm (μJ)**	**~ 1.0**
HGHG pulse length (FWHM) (ps)	**1 – 0.5**		**HGHG spectrum width (%)**	**0.1**
Spot size at 266 nm (rms, μm)	**250**		**Spot size at 89 nm (rms,μm)**	**150**


FEL seed
at 800 nm
Normal incidence
Nisus Wiggler
Modulator
Undulator
177
MeV
77 MeV
Ion Pair Imaging
Experiment
at 88 nm
NISUS pop-in
monitors
Dispersion
Magnet
RF zeroPhasing
Trim Chicane
CTR Monitor
Adjustable
Chicane
Photoinjector
30 mJ
Ti:Sapphire
Amplifier
FEL Measurements
Energy, Spectrum, Synchronization
and Pulse Length Measurements


DUV-FEL Laser System:
Ti:Sapp Osc
Regen Amp
YAG Pump Lasers





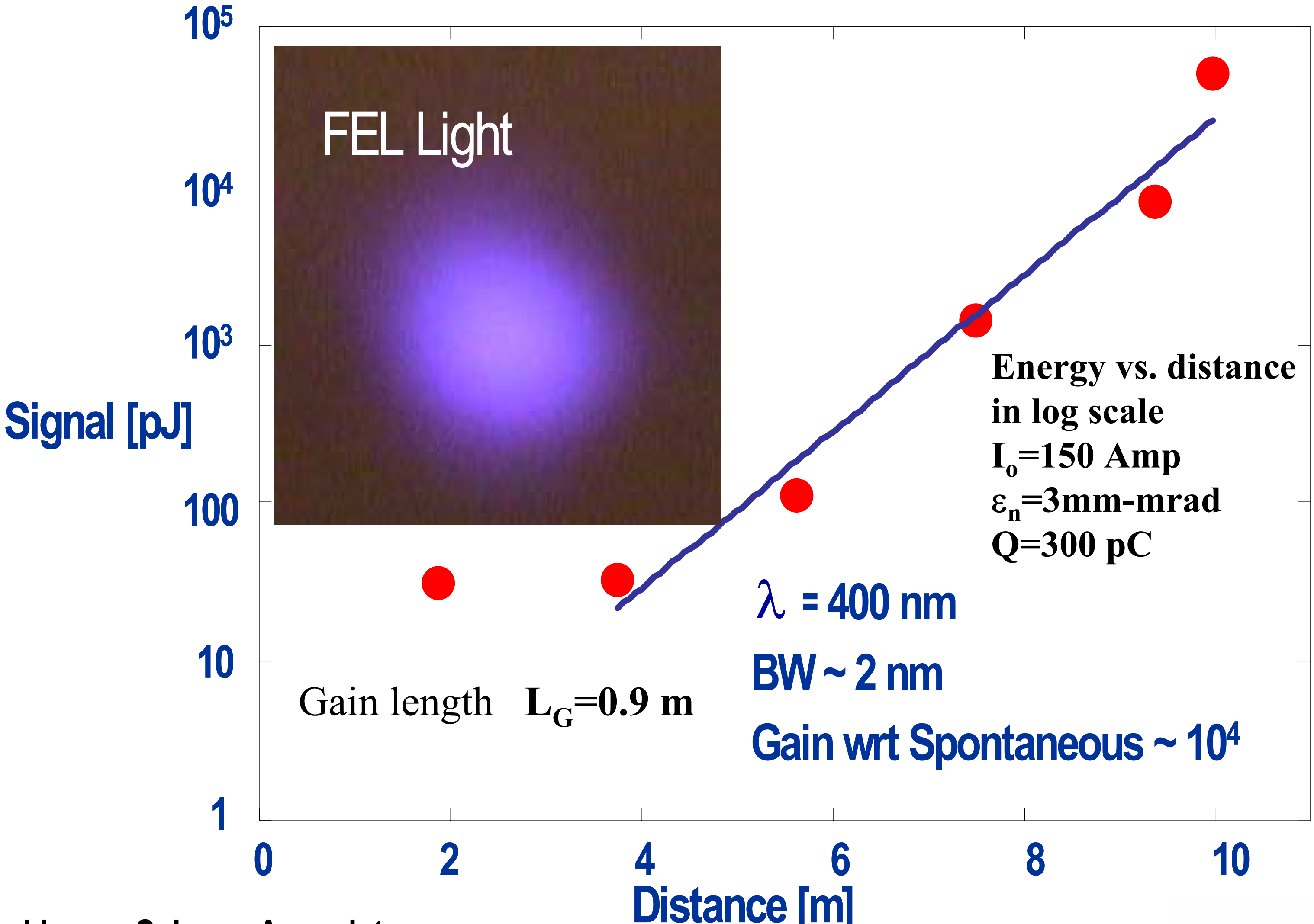
HGHG Diagnostics Station

Undulator and Electron Beam Parameters

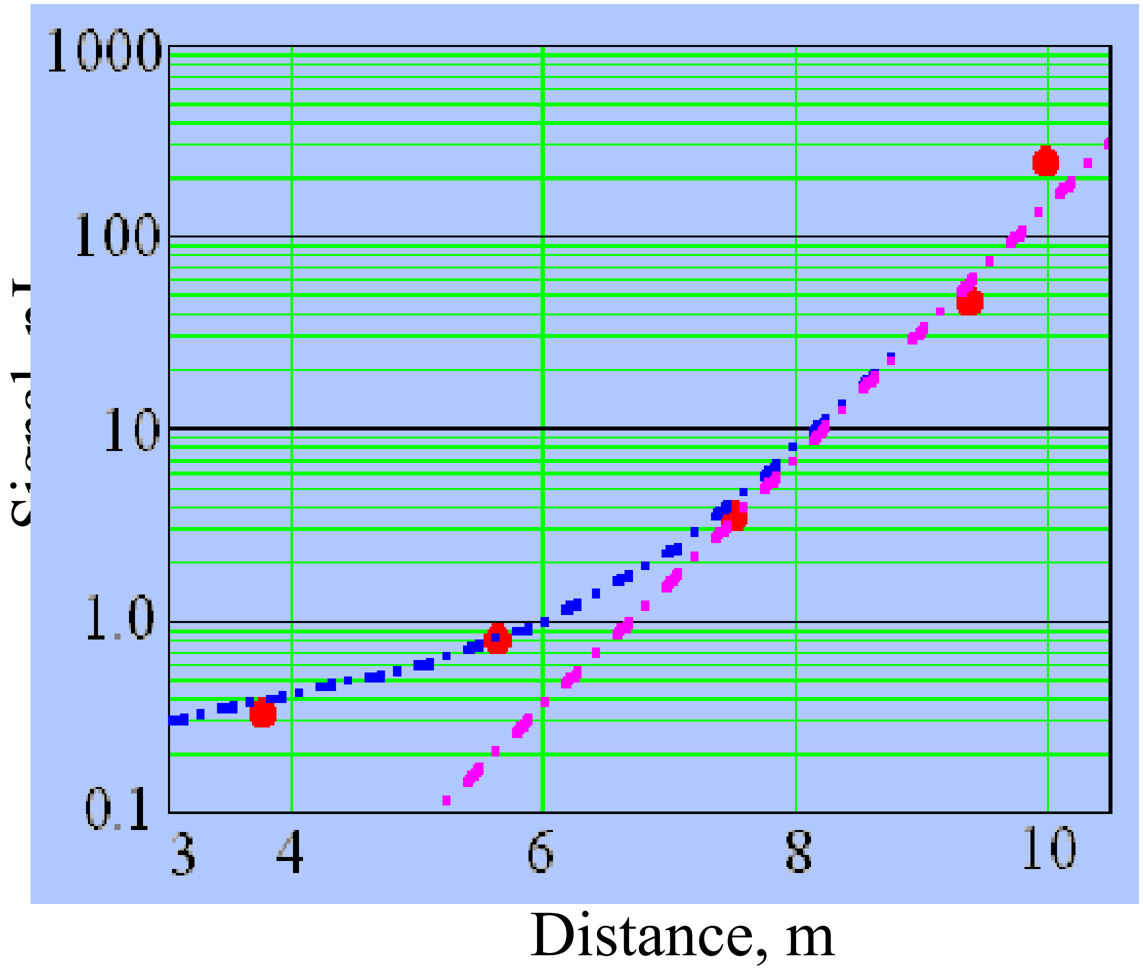
Period	3.89 cm
Number of periods (length)	256 (10 m)
Peak field	0.31 T
Betatron wavelength (at 140 MeV)	20 m
Electron beam size, RMS (4 mm mrad)	250 um

Energy	Up to 200 MeV
Charge	300 pC
Normalized emittance	4 mm*mrad
Compressed bunch length, RMS	0.3-0.6 ps
Energy spread, RMS	0.3 %

SASE Signal at DUV-FEL February 2002

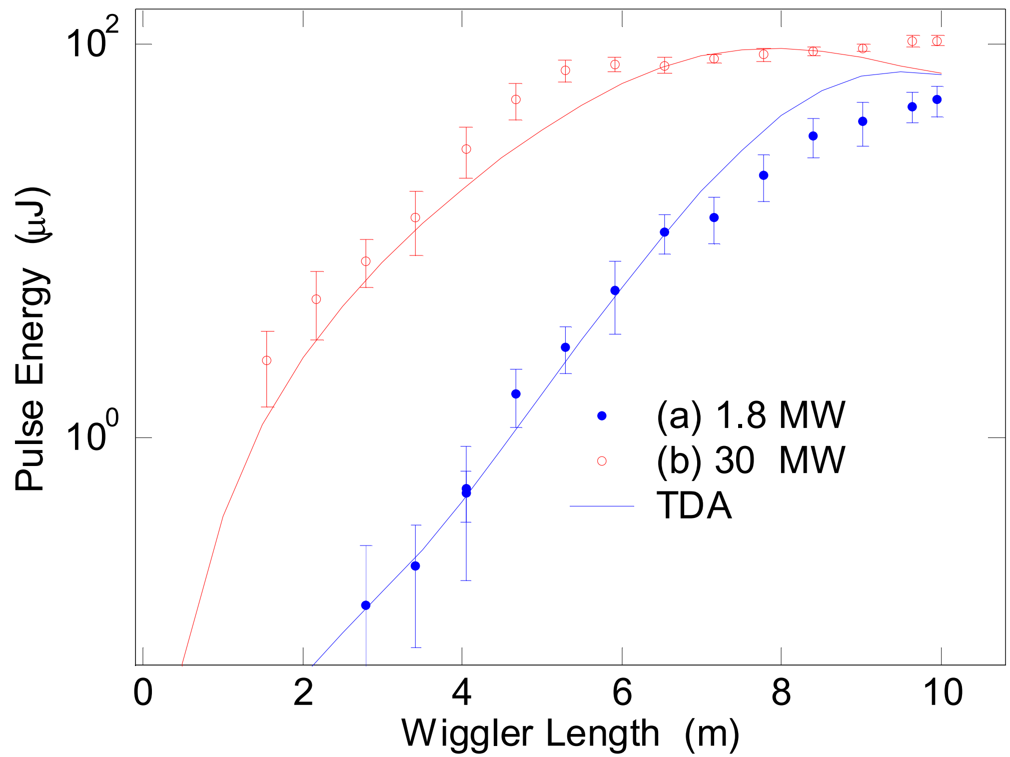


266 nm SASE Signal along NISUS Wiggler



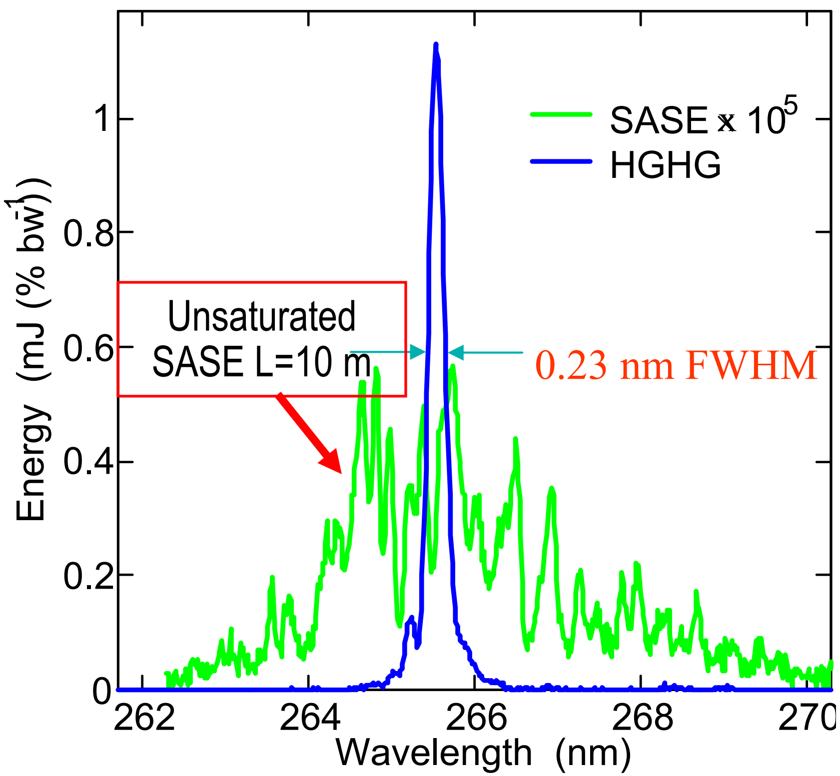
L_G= 0.66 m
I_o=550 Amp
ε_n=3 mm-mrad
Q=300 pC

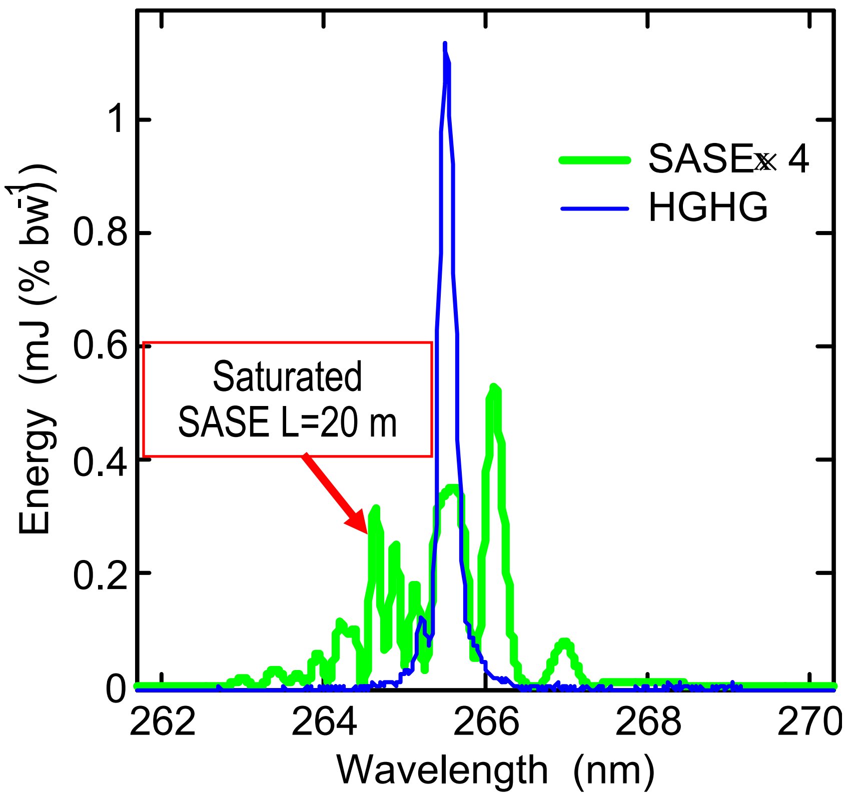
266 nm HGHG Power vs. Distance



Average output: 100 μJ, 10% fluctuation

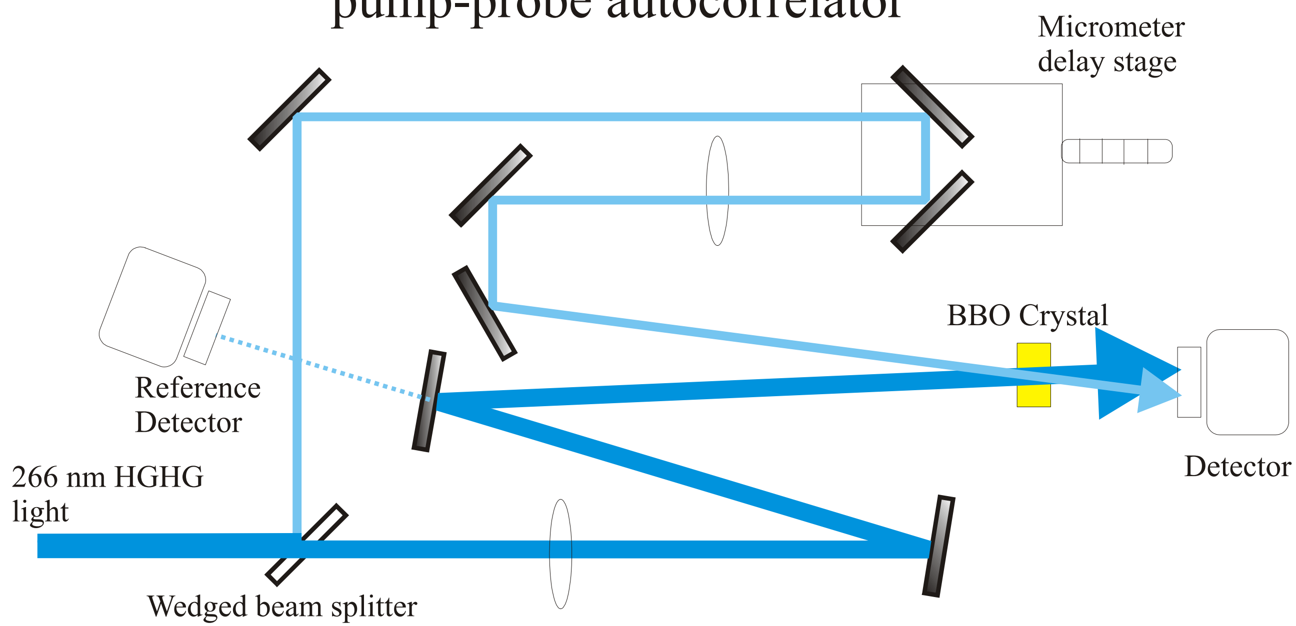
Spectrum of HGHG and SASE at 266 nm





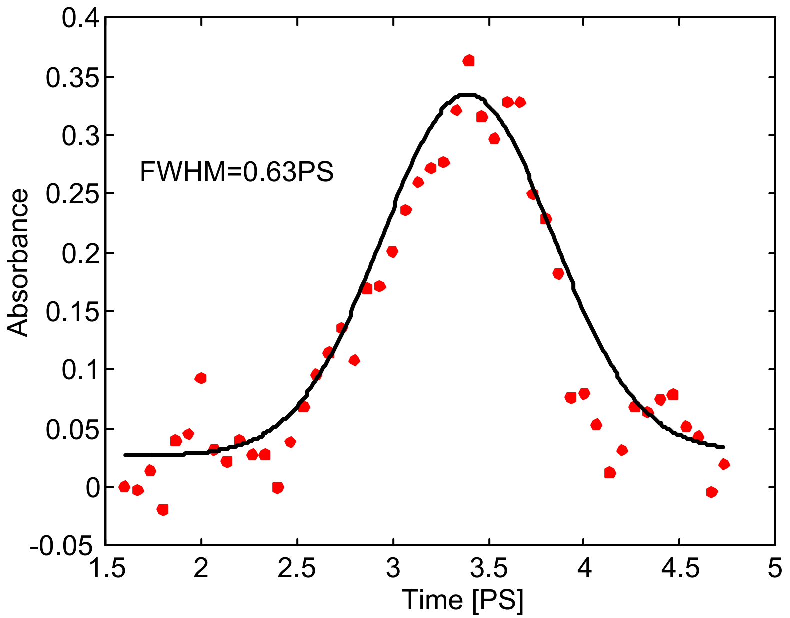
HGHG Pulse Length Measurements

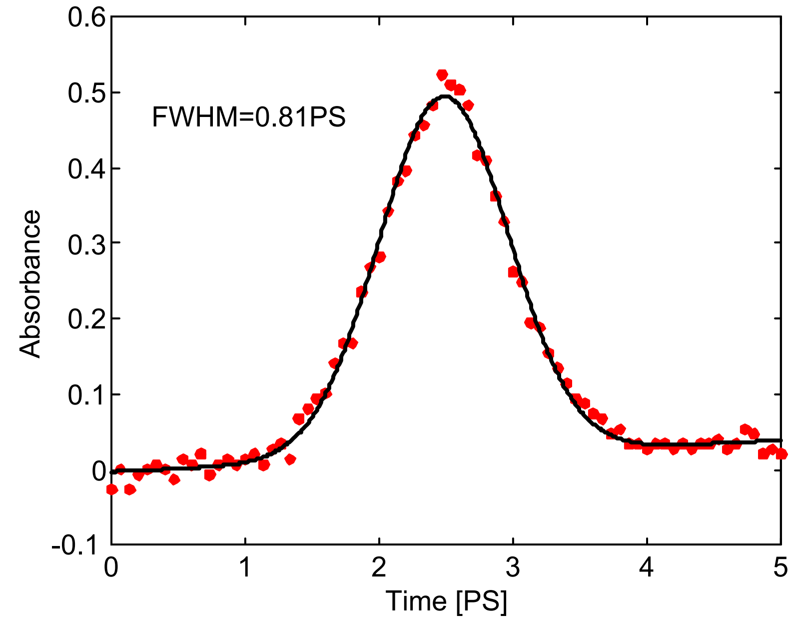
Layout of the two-photon absorption pump-probe autocorrelator



HGHG Pulse Length Measurements

Two-photon absorption pump probe
autocorrelation traces





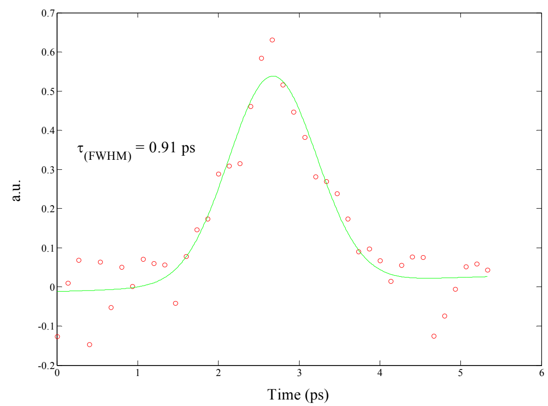
- Pulse length is 0.63 ps
- Seed laser 1.8 MW
- Saturation at the end of wiggler

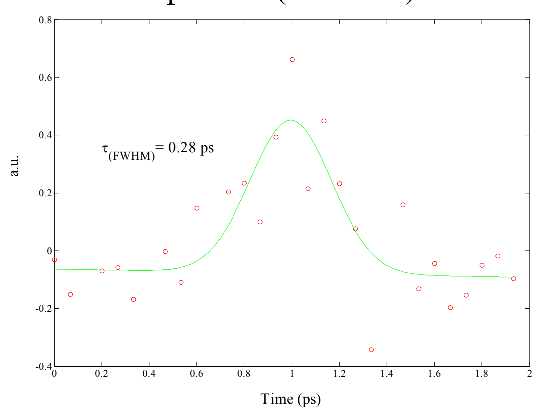
- Pulse length is 0.81 ps
- Seed laser 80 MW
- Saturation after 5 m

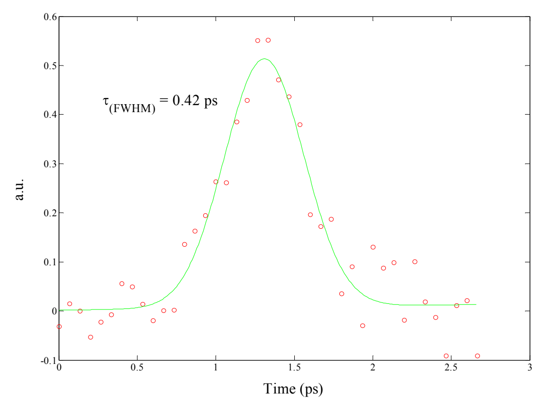
HGHG Pulse Length Control by Seed Laser

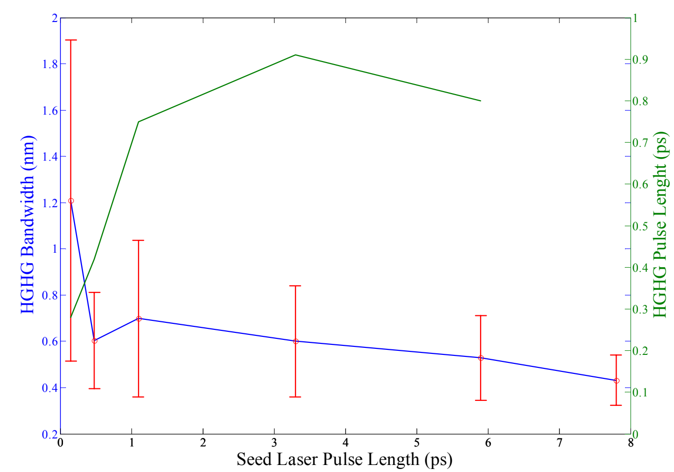
HGHG pulse was measured using two-photon absorption auto-correlator for seed laser 6 ps to 150 fs. Slippage could lead to 100 to 200 fs HGHG pulse lengthening. Possible measurement errors are:

- Resolution of micrometer (70 fs).
- Jitters .
- GVD Dispersion (70 fs/nm).





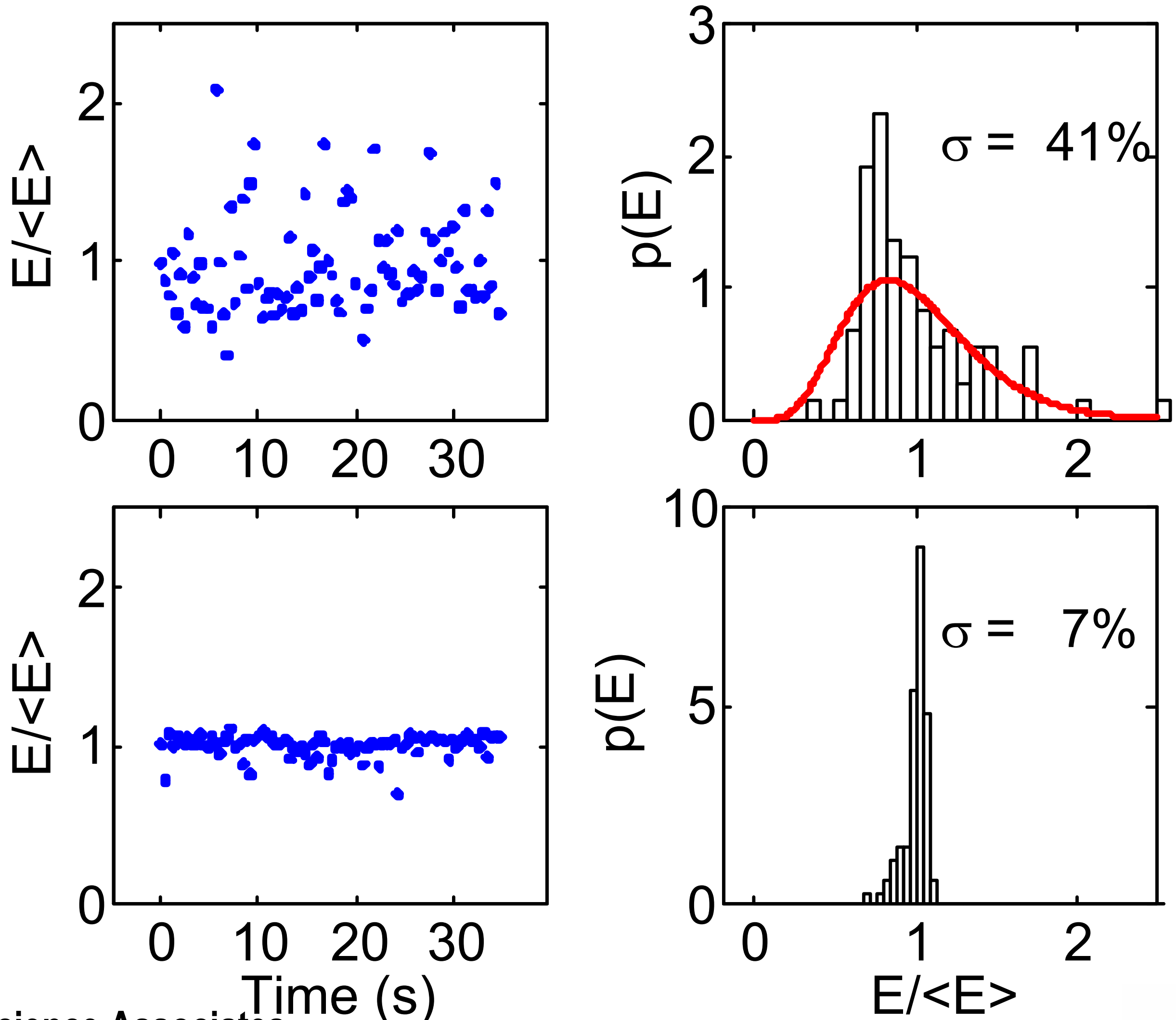




Intensity Fluctuation of SASE and HGHG

Unsaturated
SASE

HGHG

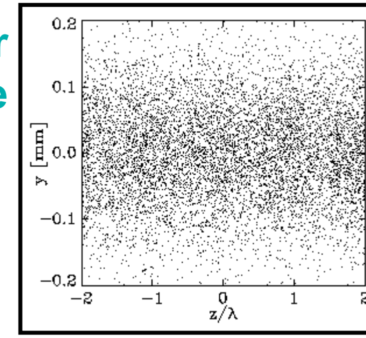


Harmonic Generation

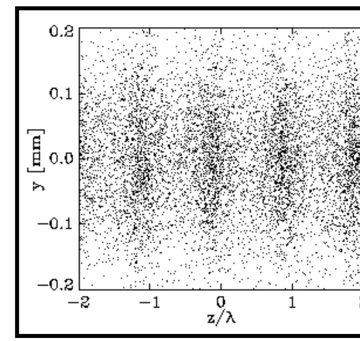
$$P_2 = P_3 \left(\frac{K}{\gamma k_u \sigma_x} \right)^2 \left(\frac{K_2}{K_3} \right)^2 \left(\frac{b_2}{b_3} \right)^2$$

$$\left(\frac{P_3^{NL}}{\rho P_{\text{beam}}} \right) \approx |H_0|^2 \frac{16 w_{1r}^3}{w_{3r}} \left(\frac{P_1}{\rho P_{\text{beam}}} \right)^3 \sim 1\,\%$$

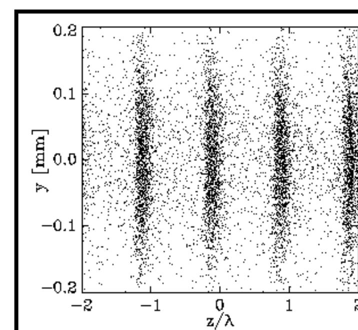
undulator entrance

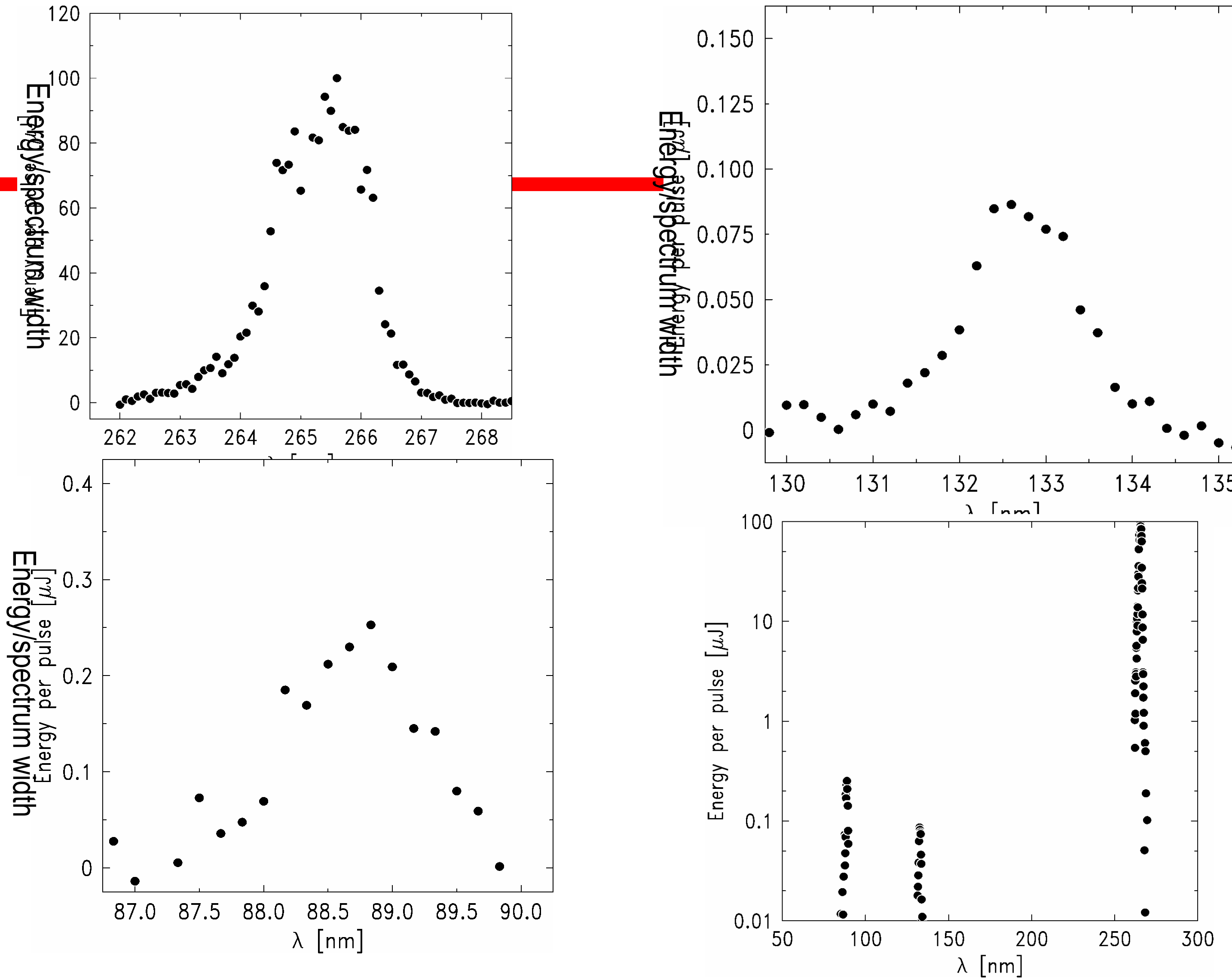


half-way saturation



full saturation

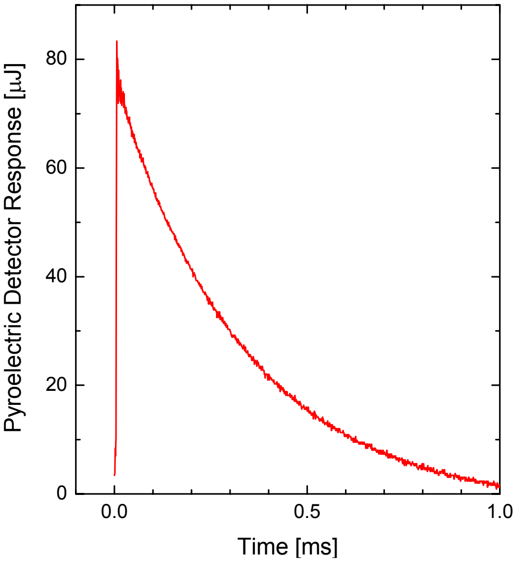




Scaled to 100 uJ for 266 nm, assumed mono has equal efficiency at 89 and 266 nm, and a factor of 2 greater at 133 nm.

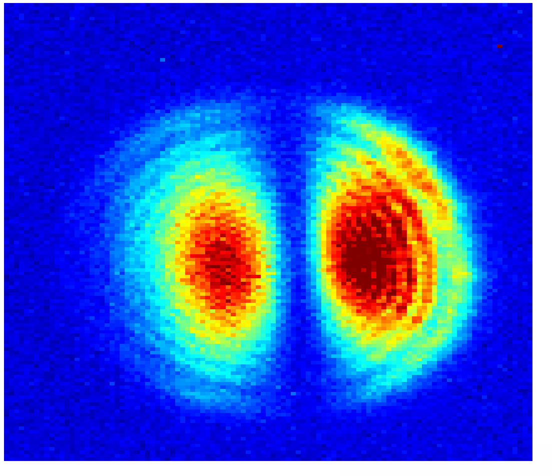
Other Capabilities at the DUV-FEL Facility

- Coherent THz Radiation
- Femto-second pulse radiolysis



Possible Future development:

- Ultra-fast plasma X-ray source.
- Femto-second electron diffraction.



XUV-FEL Scientific Opportunities

Near-term

Probing Superexcited State Dynamics

Universal Probe of Reactive Scattering

XUV Probes of Surface Dynamics
(M. G. White)

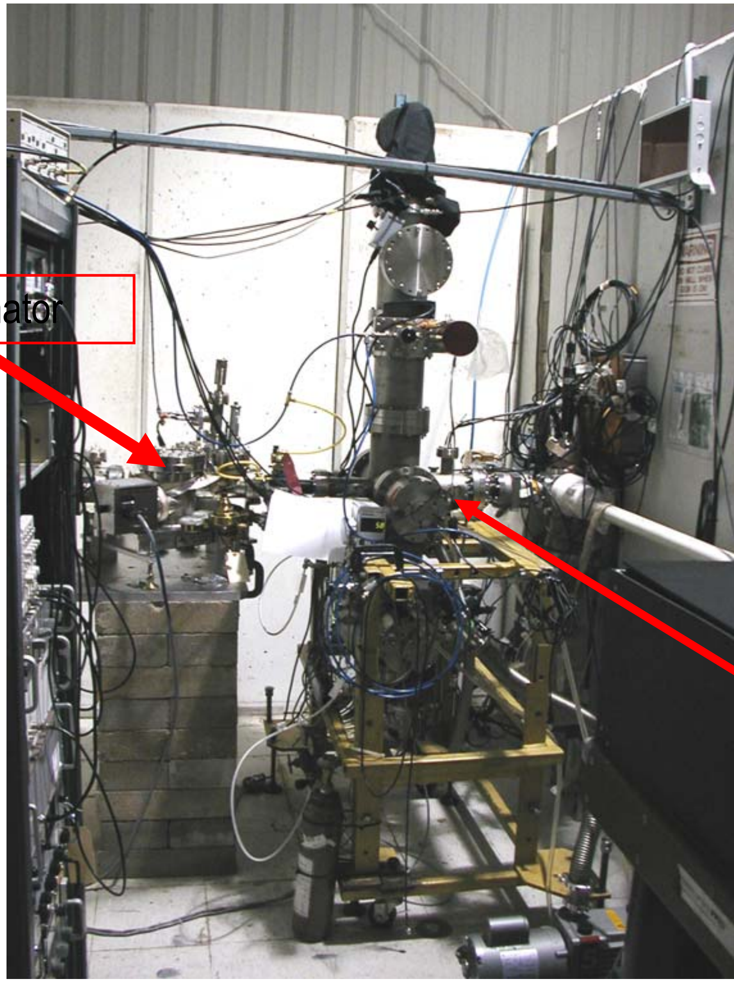
Longer-term

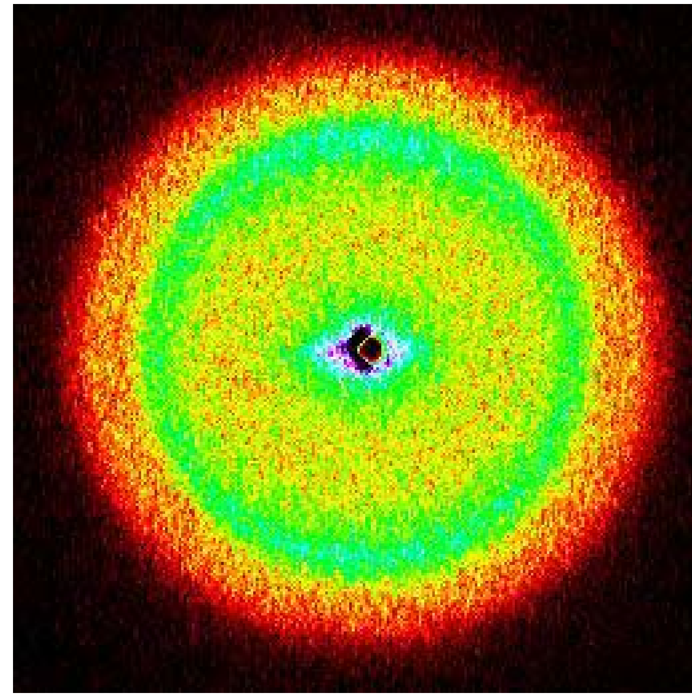
Time-resolved photoelectron imaging

Nonlinear processes in the XUV
(L. DiMauro)

Installation of the first experiment – Dec, 2002

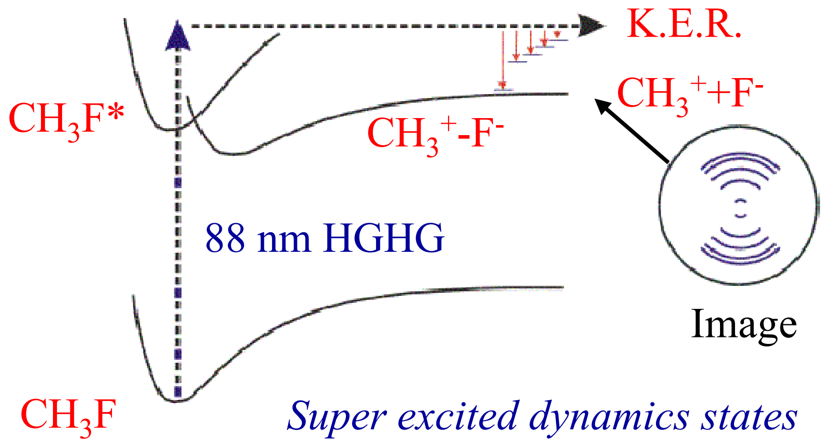
Monochromator

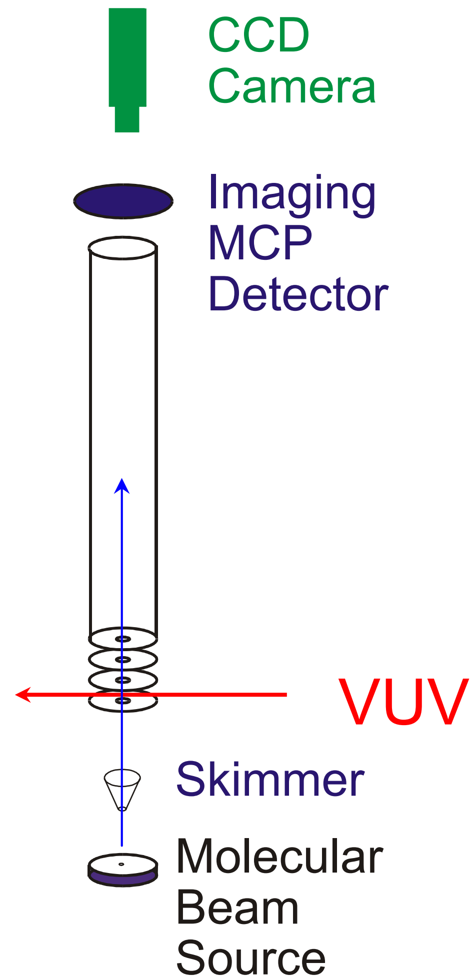




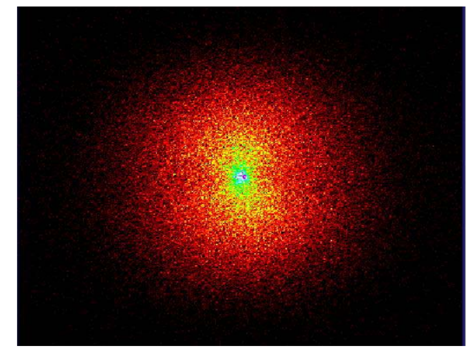
Ion Pair Imaging station

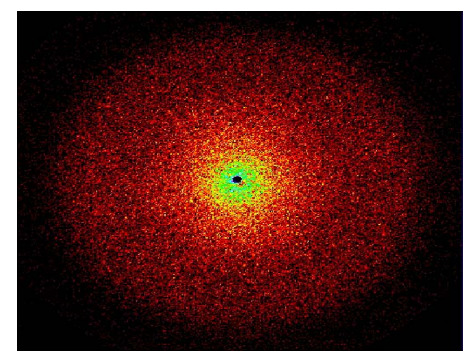
Ion Pair Imaging Spectroscopy





F^-





CH_3^+

IPIS Technique: Excitation of a molecule in the VUV/XUV accesses ion-pair states that dissociate. If one of the products is structureless (such as F^-), then the kinetic energy release directly reflects the internal energy in the other product and the dynamics of the process.

Arthur Suits, BNL Chemistry and SBU

Ion Pair Dissociation of CH_3F

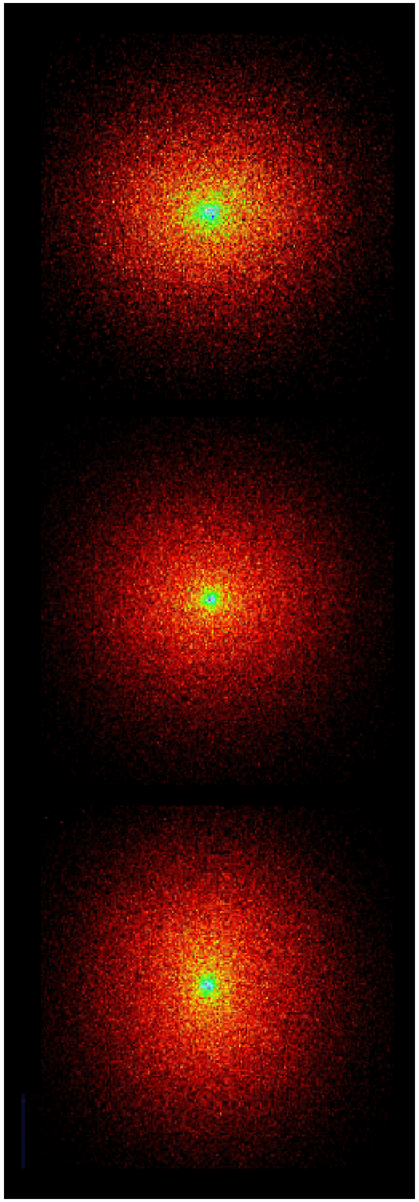
F^- Images

Photon Energy:

13.52 eV

13.68 eV

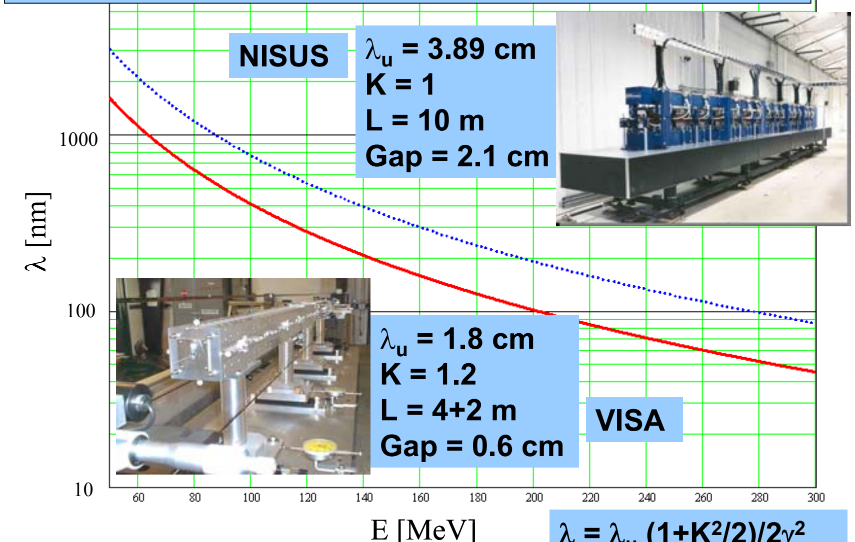
13.95 eV



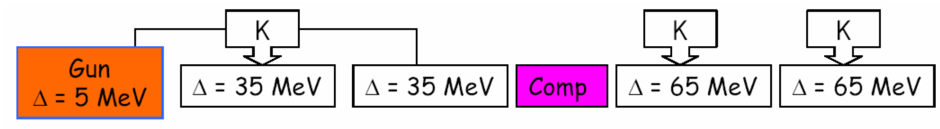
XUV Polarization

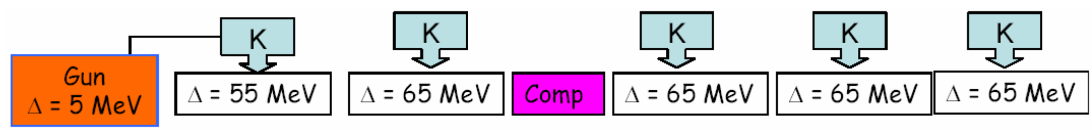
DUV-FEL Upgrade – 100 uJ at 100 nm

FEL Scaling With NISUS & VISA



$\lambda = \lambda_u (1+K^2/2)/2\gamma^2$





Summary

Tremendous progress was made in DUV-FEL in the last couple years.

We have developed a plan to upgrade DUV-FEL to 300 MeV and reach 100 nm for DUV-FEL.